Changing coastlines

The Governing Council of TERI

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Effects of climate change

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The Rising Seas

Over the last 100 years, the sea level has risen by 10–20 cm, and a more rapid rise is predicted during the next 100 years. A number of studies predict a rise ranging between 10 and 30 cm for the next four decades, a rate of increase that is significantly higher than that which has been experienced over the last 100 years.

What is this phenomenon that is causing the seas to rise? It is known as **global warming** brought about by an increase in the naturally occurring 'greenhouse effect'. The earth is enveloped by a blanket of trace gases that act in a way analogous to the glass in a greenhouse. These gases trap some of the solar radiation that reflects off the earth's surface and re-emit to the cooler atmosphere in space. The trapping of the terrestrial radiation warms the surface of the earth and the lower atmosphere. These trace gases are known as GHGs (greenhouse gases) and include water vapour, CO_2 (carbon dioxide), CFCs (chlorofluorocarbons), CH_4 (methane), N_2O (nitrous oxides), and certain trace gases. Figure 1 is a simplified diagram of the greenhouse effect.

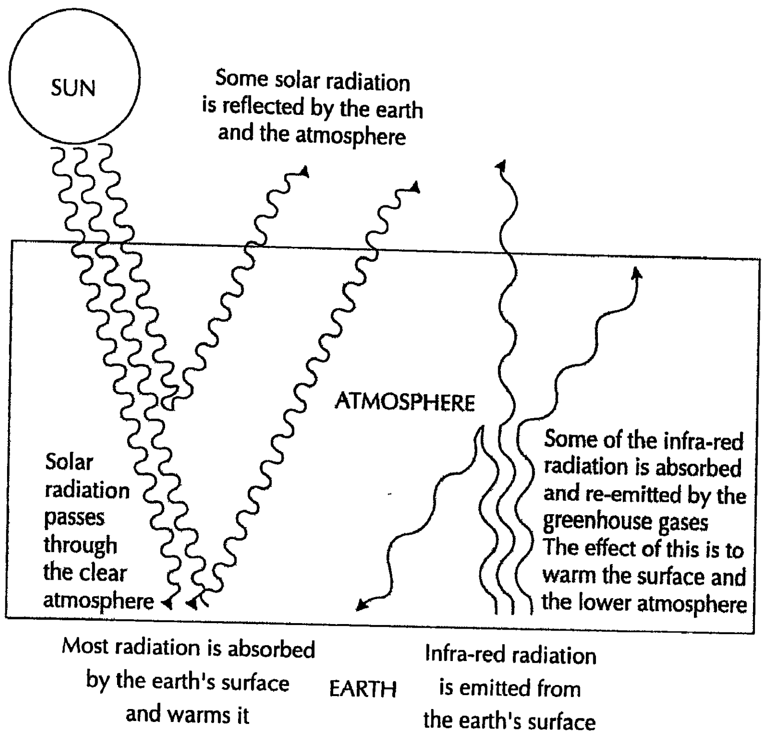


Figure 1. A simplified diagram illustrating the greenhouse effect
Source: IPCC (1990)

The issue here, however, is not this naturally occurring greenhouse effect but the **enhanced** greenhouse effect that is observed in recent times. It is believed that this is due to the **increase** in the GHGs arising out of human activities especially after the industrial revolution. Ice cores indicate significant increases in the concentrations of the radiatively active gases such as CO_2, CH_4, and N_2O since the beginning of the industrial revolution. Moreover, there has also been an increase in industrial CFCs. (Table 1). This increase in GHG concentrations is expected to result in a climate change due to the increased warming effect.

The contribution of CO_2 has been the largest of the various gases responsible for an increase in climate forcing, followed by

Table 1. Summary of key GHGs influenced by human activities

	CO_2	CH_4	CFC-12	N_2O
Atmospheric concentration	ppmv*	ppbv**	pptv	ppbv
Pre-industrial (1750–1800)	280	700	0	275
Present day (1994)	358	1720	503	311
Current change per year	1.5 (0 4%)	10 (0.6%)	18–20 (4%)	0.8 (0.25%)
Atmospheric lifetime (years)	(50–200)	12–17	102	120

*parts per million by volume
**parts per billion by volume
Sources: IPCC, Climate Change 1994, p 25; IPCC, Climate Change 1995, p 19.

that of the CFCs, CH_4 and N_2O. The relative contributions for the period 1980–1990 are given in the pie diagram (Figure 2).

The main human activities that affect the sources and sinks of CO_2 are fossil fuel use and changes in land use such as deforestation is evident. Before 1860, the atmosphere contained about 280 ppmv and by 1994, it stood at 358 ppmv. A major reason for this increase in CO_2 has been the greater use of fossil fuels namely coal, oil, and natural gas which have been so much part of the energy base that has fuelled the industrial and post industrial revolutions, especially since 1950. The cumulative release of CO_2 from fossil use and cement manufacturing from 1850–1987 is estimated at 200 GtC (Giga tonnes of carbon) within a ±10% band of uncertainty. The total biotic carbon release from changes in land uses, primarily deforestation, has been estimated to be about 115 GtC between 1850 and 1985, with an uncertainty band of ±30%. The current annual release of carbon dioxide from fossil fuels (about 6 btC/y) is about three times that of biotic releases.

It has been established that the major responsibility for the increase in GHG concentration lies with the developed nations of the world, since the bulk of cumulative emissions of these gases have been produced by them. However, with the relatively rapid growth taking place in several developing countries, a growth that is also energy-driven and resource intensive, it is likely that future emissions from these nations will constitute an enhanced share of the total.

According to IPCC (Intergovernmental Panel on Climate Change) if nothing changes and human activity continues as at present, what is termed as BAU (Business as Usual) scenario, surface temperatures will increase by about 2 °C between 1990 and 2100; lowest estimate being 1 °C and highest estimate at about 3.5 °C.

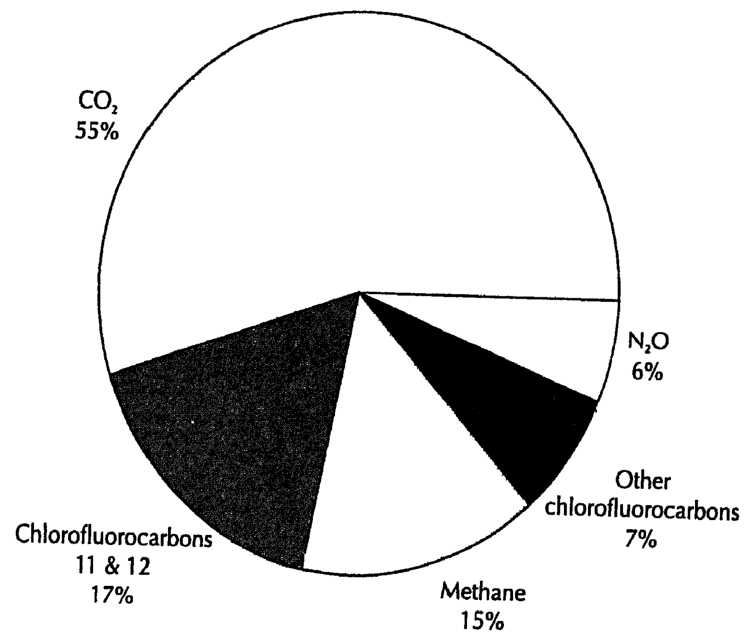


Figure 2. GHG contribution to radiative forcing, 1980–1990
Source: IPCC-1 (1990)

Table 2. Contribution to GHG emissions by activities (% of total gas emissions)

Activity	Share (%)	GHG emission
Fossil fuel use	81	
Deforestation	17	CO_2
Cement manufacture	2	
Paddy cultivation	30	
Livestock	20	
Biomass burning	17	CH_4
Landfills	11	
Coal mining	9	
Natural gas	12	
Fossil fuel use	43	
Fertilizer use	25	
Biomass burning	25	N_2O
Cultivated lands	7	
Industrial activity	100	CFCs

Source: D Ahuja (1989)

Climatic changes at the regional level are predicted with far lower levels of confidence. However, there is a broad consensus that global warming will tend to be higher in the higher latitudes in late autumn and winter than in the tropics. Annual average runoff is also expected to be greater in the higher latitudes. Higher snowfall in winter is expected in the higher latitudes, higher precipitation in the summer in the tropics and perhaps reduced precipitation in summer in the mid-latitudes.

As the earth warms up, three consequences can be predicted: (i) the sea water will expand, (ii) the glaciers will begin to melt, and (iii) the polar ice sheets of the Arctic and the Antarctica will begin to thin. The result of these will be an increase in the volume of sea water and a consequent rise in its level.

Studies relating to SLR (sea level rise) are uncertain with regard to its extent and timing. IPCC 1 (1990) projections, based on its various scenarios, are SLR of 18 cm by 2030 as the best estimate and 8 cm as the low estimate with 29 cm being the high one in a scenario with no limitations of GHGs. In the year 2070, the expected rise will be between 21 and 71 cm, with a best estimate of 44 cm; and by 2100, a 110 cm sea level rise is predicted as a high case, 66 cm as a best case and 31 cm as a low case (Figure 3). The major contribution to SLR is estimated to derive from a thermal expansion of sea water. (Figure 4). The uncertainty in projections is evident in the estimates of SLR expected in the year 2100 by various studies as seen in Table 3.

From the point of view of a region or a country, however, it is not this eustatic SLR that is of policy relevance, but the relative mean sea level change. This is the difference between the eustatic rise and any local change in land elevation brought about by tectonic movements, glacial rebound, or by subsidence or compaction resulting from mineral and/or groundwater extraction and drainage. Thus the change in relative sea level will vary among regions of the world depending on these local factors.

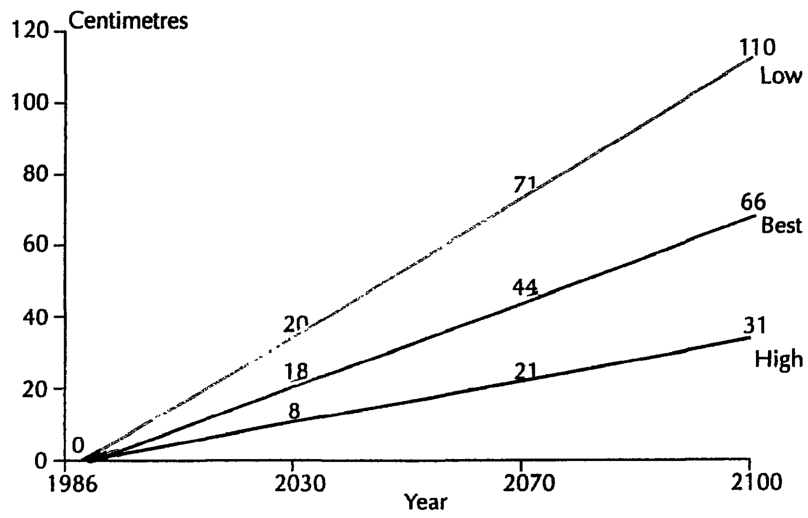


Figure 3. Global sea level rise, 1985–2100 (BAU scenario)
Source: IPCC-1 (1990)

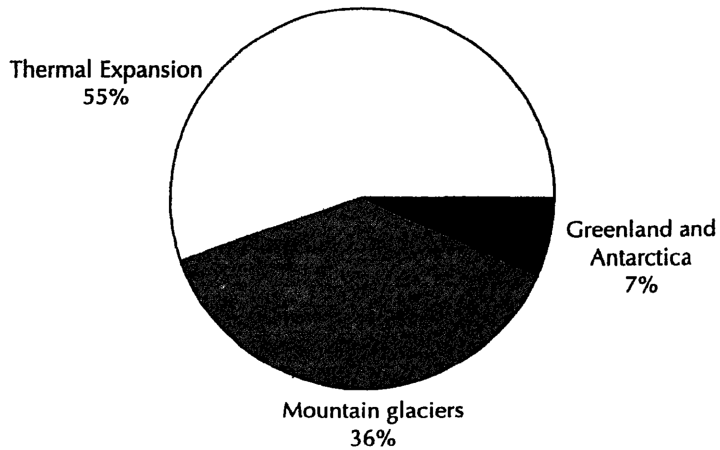


Figure 4. Contributions to SLR (cms), 1985–2030
Source: IPCC-1 (1990), pp 276

Table 3. Scenarios of SLR in 2100 (in cm)

Sources	Year 2100
EPA (1983)	56–345
Hoffman *et al* (1986)	57–368
IPCC (1990)	31–110
Wigley and Raper (1993)	3–124
IPCC (1995)	15–95*

*IPCC, 1995. *Climate Change 1995: The Science of Climate Change*, WMO and UNEP.

The Impacts

The primary physical effects of a SLR are expected to be, increased coastal flooding, greater erosion, stronger storm surges, and higher wave activity. These in turn could have (i) ecological effects such as loss of wetlands, coastal vegetation and habitats, salt intrusion into ground water systems and loss of cultivable land, and (ii) socio-economic and legal/institutional implications for coastal area development. Chart 1 broadly summarizes the possible effects of a SLR.

Ecosystems that can be affected by SLR include coral reefs, mangrove ecosystems, and the arctic marine ecosystem. Based on the SLR projections by the IPCC, reef systems are not expected to be threatened. However, higher wave activity may result in greater erosion of reef flats and exposed reefs where land is already sinking. Mangrove ecosystems are, in general, found in the intertidal areas.

Sea-level position is central to the functional ecology of a mangrove swamp. Rise in sea level will perturb every aspect of the ecosystem, and combined with effects of climate change, stresses from storms and human disturbances, the world's mangroves are likely to face severe disruption in the next few decades (Ellison, 1992).

Submergence of mangroves will be disastrous for those who are dependent on them for a livelihood as they are economically productive areas and their contribution to the protection/preservation of the environment is valuable. In Bangladesh, for example, it is estimated that about 30% of the population depends to some extent on the mangrove environment for their livelihood. In Sri Lanka too, the dependence is high with estimated average monthly incomes from mangrove products to be about US $55 (SAARC, 1992).

Chart 1. Possible effects of SLR

I Physical effects	– increased flood damage – storm surge – shoreline retreat – increased sedimentation – changes in river flow rates – higher wave activity – increased land subsidence
II Ecological effects	– loss of coastal wetlands – salt water intrusion – evaporation of solar ponds – loss of coastal vegetation – loss of coastal habitats – loss of cultivable lands – loss of non-commercial biomass
III Socio-economic effects	– loss of human settlements – loss of structures and property – loss of coastal communities – loss of life from increased and sudden storm surges – changed set of economic activities – increased flood insurance costs – loss of social amenities – increased flood control costs
IV Legal/Institutional effects	– change in coastal zone management practices – new organizations to handle SLR – impact on taxes and laws – delimitation of maritime boundaries

Source: Noronha L (1990)

The estimated relative effects of a 35 cm SLR by 2050 AD on ecosystems are given in Chart 2.[1]

Coastal areas are historically the most densely populated regions of the world. The richest and most productive agricultural areas are also found in the low-lying lands along the coast. Because of access to the maritime transport, these regions have become the centres of trade. Half of the world's fastest growing cities in terms of population and economic activity are located at the mouth of rivers. Some of island states have capitals which are often near or just above mean sea level.

SLR could have socio-economic effects arising from loss of property, loss of recreational beaches, increased flood insurance costs, loss to coastal communities from tourism and near-shore fishing and impact on human health. These in turn could have legal and institutional implications for coastal zone management practices, for taxation and legislation and for the delimitation of national boundaries. Chart 3 provides some of the impacts of SLR on coastal zone activity.

Chart 2. Relative effects on ecosystems

	Tropical/ subtropical	Ecosystems mid-latitude	Polar/ subpolar
Deltas	H	H	H
Estuaries	M	M	M
Wetlands	M	M	M
Coastal plains	M	M	L
Coral reefs	L	H	–
Lagoons	M	M	M
Mangroves	H	–	–
Ice margin	–	L	M
Seagrass beds	M	M	L
Fisheries	M	M	L
Rivers	L	L	L
Coastal lakes	L	L	M
Beaches	H	H	H

L = Low impact, M = Medium impact, H = High impact, – = not applicable
Source: IPCC (1992A)

Chart 3. Possible SLR impacts on coastal zone activity

Coastal Zone Activity	How it may be Impacted
Agriculture	By increased tidal activity and salt water intrusion
Exploitation of mangrove resources	If mangroves disappear due to an inability to migrate inwards
Solar salt making	Through erosion and flooding of salt ponds/ pans
Nearshore fishing	If fish habitats in reefs, estuaries are disturbed or fishing grounds shifted
Aquaculture	If brackish water ponds are submerged or inundated
Tourism	If beach fronts are eroded or beaches and tourist infrastructure is inundated
Power plants, refineries, etc.	By inundation if in low lying areas or by storm surges
Residential, commercial, services	Shoreline movements may lead to a reduction in land availability
Port facilities	Due to higher storm surges or flooding

The vulnerable ones

A country is said to be vulnerable to SLR if:

(i) large sections of its coastline are low-lying, narrow, or if its average height above mean sea level is low;
(ii) it has a dense population in the low lying areas;
(iii) the physically vulnerable coastal region supports considerable economic activity, which makes a significant contribution to the country's total GDP (gross domestic product); and

[1] This chart considers only the impacts of SLR and is not intended to include the numerous environmental stresses that these ecosystems are experiencing from other local anthropogenic effects.

(iv) the country has a limited ability to diversify its coast or marine based economic activity

This makes the small island developing countries of the world particularly vulnerable. These include island states such as Tuvalu, Vanuatu, Kiribati, Marshall Islands, the Solomon Islands, Sao Tome and Principe, Mauritius, Maldives, Seychelles, and Comores. All these islands are remote, dependent on foreign trade, with essentially marine oriented, economies, and have high population densities. These countries are vulnerable on two counts: (i) the actual SLR, in some cases, can wipe out the whole country (those with average height of less than three metres), and (ii) the threat to their survival and development arising from the loss of the country's resource base, which is often the country's only resource base, e.g., through the bleaching and death of coral reefs, the disappearance of marine species, etc. Because of their remoteness, size, and the generally unskilled labour force, it is almost impossible for them to switch from marine based development to other alternatives. It is evident that these countries face a problem that is certainly not of their making, and it is therefore, essential that they be provided with whatever material, capital, informational and resources support necessary to cope with, and respond to the potential problem.

An UNEP (United Nations Environment Program) study placed 27 countries in its list of countries vulnerable to a SLR. These countries are Argentina, Bangladesh, Brazil, Burma, Caribbean, China, Colombia, Egypt, Ecuador, India, Indonesia, Kenya, Maldives, Malaysia, Mozambique, Nigeria, Pacific Islands, Pakistan, The Philippines, Senegal, Surinam, Sri Lanka, Taiwan, Thailand, The Gambia, Venezuela, and Vietnam (UNEP, 1989). Of these countries, six are from South Asia, with Bangladesh, Pakistan and the Maldives being in the list of the ten most vulnerable. Most of these countries have low coasts, large deltas and estuaries, and are already prone to sea erosion and\or cyclones and floods. Of the total coral reef area in the world, 24% lies in the Indian ocean; large tracts of mangrove ecosystems and some of the largest deltas in the world too are in this area. Table 4 below summarizes the coastal features of South Asian countries that have a bearing on their vulnerability to SLR.

Table 4. Coastal features of South Asian Countries of relevance to SLR

	Major deltas	% Urban Pop in coastal cities	Coastline < 100 m above MSL	Coral reefs	Mangrove forests	Length of Coast-line
Bangladesh	*	32	*	*	*	580
Pakistan	*	34	*	*	*	1046
Sri Lanka	*	84	*	*	*	1340
India	*	27	*	*	*	9000
Maldives	–	100	*	*	*	644

*significant
Source SAARC (1992)

Findings of country case studies

Rising seas do not differentiate between the developed and the developing world, but coping with the problem may differ due to different capabilities and initial conditions. Several case studies from both the developing and developed world provide some preliminary idea of the possible impact of SLR.

From the developing world

Bangladesh. A one metre SLR is expected to be disastrous to Bangladesh because of its high population density, low lying land, economic activity located in the impacted area and its relatively low ability to respond and adapt to the threat of SLR. Over 110 million people in Bangladesh live in an area of 144 000 km^2. Two of the country's major ports are on the coast, as is the major tourist beach at Cox's Bazaar, the world's largest mangrove for-

est (the Sunderbans), a number of islands, extensive shrimp farms, as well as agricultural land. While all of these are likely to be at risk due to any increase in sea level, the impact will not be restricted to the coastal zone.

One study estimated that about 7% of the country's habitable land, 5% of the nation's present population and over 5% of the nation's agricultural output originates in the area affected by a 1 m rise (Broadus, 1993). The study estimated that the present discounted value of the economic loss in Bangladesh by 2050 AD of an unchecked 1 m SLR would be of the order of 1% to 2% of its current GDP.

Other studies estimate that the land at risk supports over 14 million head of livestock, 100 000 households engaged in light industry, 8000 schools, 1500 km of railways, 20 000 km of roads, and other valuable facilities. In addition, the rise in sea level would lead to frequent inundation of land at higher levels as water is 'backed up' into the river systems which dominate Bangladesh. One of the economic consequences would be the loss of the salt-sensitive rice crop grown in these areas. Rising sea levels and increased salinity also threaten 4000 km^2 of mangrove swamps which are valuable both on their own account and for the protection against erosion which they offer.

Egypt. The area that could be affected by a 1 m SLR in Egypt represents approximately 12–15% of the nation's arable land and a population of about 7.5 million people (14%). It is estimated that approximately 14% of Egypt's current GDP, which originates in the area, is also likely to be affected (Broadus 1993).

The IPCC (1992B) estimated that coastal erosion along the Nile delta that would result from a 1 m rise would cause a loss of 100 km^2 of land, including residential and recreational areas. The estimated value of these losses is $0.6 billion. Parts of the delta and Alexandria would be inundated, affecting about 5 million people (10% of Egypt's population) and substantial investments in agriculture, fisheries, ports and infrastructure along the coast.

The Maldives. One of the most vulnerable nations is the island state of the Maldives. The state includes about 1300 islands, 275 of which are inhabited and almost all of which are used economically for forestry and other purposes. Its population is concentrated on 25 islands, most of which is in the capital island, Male. Fast growing populations, a large demand for land and housing, and other social and physical infrastructure have been mostly at the expense of the island's freshwater supplies and natural sea defences. Virtually the whole of the country's population, infrastructure, and economy lies between 80 cm and 2 m above sea level. Rising sea levels, salt water intrusion and increased ground water withdrawals due to increased demand for water will tend to damage the island's freshwater aquifers.

From the developed world

The Netherlands. The Netherlands is densely populated with productive and highly valuable economic areas lying below mean sea level. About 65% of the GNP (gross national product) is earned in the low lying coastal zone. Large parts of the Netherlands have been created by reclamation from the sea, and almost half consists of land less than 5 m above sea level. The Netherlands coastline is protected from the sea in two ways: one half has sand dunes and the other half has dykes. It is expected that each of these coastal stretches will respond differently to an increase in sea level, although both will be under increasing pressure as the sea rises.

SLR of 50 cm is expected to increase flooding in the low-lying areas of the Netherlands from once in 10 000 years to once in 2000 years, a fivefold rise in frequency. Since a third of the Netherlands is below today's sea level and another quarter is less than a metre above it, rising seas will involve the setting up of protective structures and therefore lead to further expenditure which the nation can hardly afford. A 1 m SLR, which will require the taking of water management measures, is expected to

cost each year less than 0.1% of the country's annual GNP. However, more than a third of the country's coastal wetlands would be degraded because they cannot migrate inland or adapt because of sediment shortages. This would have serious consequences for fisheries and other natural resources (Ince 1990; IPCC 1992B).

Japan. Increased inundation and flooding is expected to be the primary impact of the rising seas in Japan. At present, even under normal conditions, about 861 km^2 area is below mean high water level. There are about two million people residing in this zone, with capital assets worth about US $450 billion. At the expected time of a 1 m SLR, this zone will have expanded to 2 340 km^2, or 2.7 times the present size. The population by then will be 4.1 million, and the assets worth US $908 billion. These are equivalent to 0.6, 3.0, and 4.0% of the total area, population and assets, of Japan respectively. However, the flood prone area, which is currently 6270 km^2, is expected to expand to 8900 km^2 for 1 m SLR. More than 15 million people are expected to be endangered. The Japanese society relies on a huge infrastructure to develop and maintain the socio-economic activities in the coastal zones. If SLR should damage this infrastructure, the impact will spread to the socio-economic systems as a whole (CGER 1993).

The United States of America. The first nationwide assessment of the primary impact of SLR of 50 to 300 cm on the United States was done by Smith and Tirpak (1989). According to this study, rising sea levels will have a profound impact on the coastal wetlands and a significant impact on coastal lowlands. With a probable rise of 1 m by 2100, 65% of the coastal marshes and swamps of the USA could be lost. It is also expected that unprotected barrier islands would be lost through accelerated erosion; and low lying coastal cities such as Charleston, South Carolina, and Long Beach Mississippi could be submerged if timely protective measures are not taken. The potential loss of coastal wetlands would be the greatest in Louisiana. Some of the most important vulnerable areas are the recreational barrier islands and spits (peninsulas) of the Atlantic and Gulf coasts.

According to IPCC (1992B), a 1 m rise in sea level would inundate 20 000 km^2 of dry land and another 20 000 km^2 of wetlands, mainly along the Atlantic and Gulf coasts. Flood risks would increase for 6.8 million households located in coastal flood plains, doubling the costs of federal flood insurance. The environmental and economic implications are serious especially for the Mississippi delta, which is already losing 100 km^2 per year.

India. Analysis of historical tide gauge data along peninsular India shows an average rise of sea level by 0.67 mm/year as against the global average of 1.8 mm/year. Impact assessments made on a 1 m SLR scenario indicate that for India (JNU 1993).

(i) A total area of 5763 km^2 of a total area of coastal states of 1.4×10^6 km^2 or 0.41% will be directly affected.

(ii) In these states, a total number of 7.1 million people are estimated to be at risk which represents 4.6% of the total coastal population.

(iii) The most vulnerable areas of the coast are the Gujarat (Kutch region), Northern Malabar (Mumbai), Southern Kerala and the deltas of River Cauvery (Tamil Nadu), Krishna and Godavari (Andhra Pradesh), Mahanadi (Orissa) and Ganges (West Bengal).

The Lakshadweep archipelago off the south-east coast of India consists of 27 separate coral reefs and islands with a total area of 32 km^2. Some of these are most densely populated regions of the country. The Lakshadweep islands are low lying with the highest point on the islands, generally, not higher than a few meters above the sea level and hence extremely vulnerable to SLR.

The Andaman and Nicobar islands, with a combined area of 8293 km^2 and a region of low population density, represent the unsunken remnants of territorial mountains. The Andamans include 204 islands and islets. The Nicobar have 12 inhabited and 7 uninhabited islands. The topography of Andaman and

Nicobar has steeper slopes, the maximum altitude of islands often exceeding 100 m. Hence the danger from inundation due to SLR in this archipelago is small in comparison to that in the Lakshadweep; but the frequency of storm, which generally originates in the Bay of Bengal, is, however, higher in the Andamans and Nicobar than in Lakshadweep. As the sea level rises, the fresh water aquifer of the islands may get polluted by saline water intrusion, and will need to be suitably recharged.

Table 5 presents some general features of India's coastal states that are of relevance to the phenomenon of a SLR. The area and population estimated to be affected in the coastal states of India vary considerably as evident from Figures 5 & 6.

Table 5. Features of coastal states and union territories

State/Union Territory	Length of coastline (km)	Coastal population* (millions)	Coastal pop. density (p/km^2)	Wetland area (km^2)
Gujarat	1600	22.87	192	28500
Maharashtra	720	19.4	631	932**
Goa	105	1.17	316	
Karnataka	300	3.92	209	173
Kerala	560	23.78	966	2203
Tamil Nadu	950	19.62	553	9481
Andhra Pradesh	1014	28.7	309	8665
Orissa	720	15.1	376	5134
West Bengal	950	21.3	757	5778
Lakshadweep Islands	NA	0.052	1615	NA
Andaman and Nicobar Islands	NA	0.278	33	2198

*refers to population of coastal districts **Includes Goa NA: not available
Source: Space application Centre (1992); CMIE (1993)

Coastal wetlands are particularly vulnerable to a SLR. The areas under major wetland categories on the Indian coast are given in Table 6.

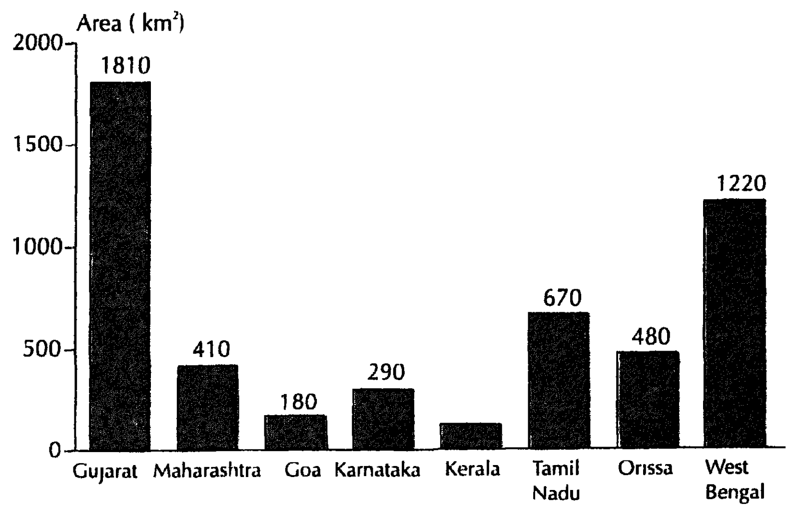


Figure 5 Area at risk, Indian coastal states
Source: JNU (1993)

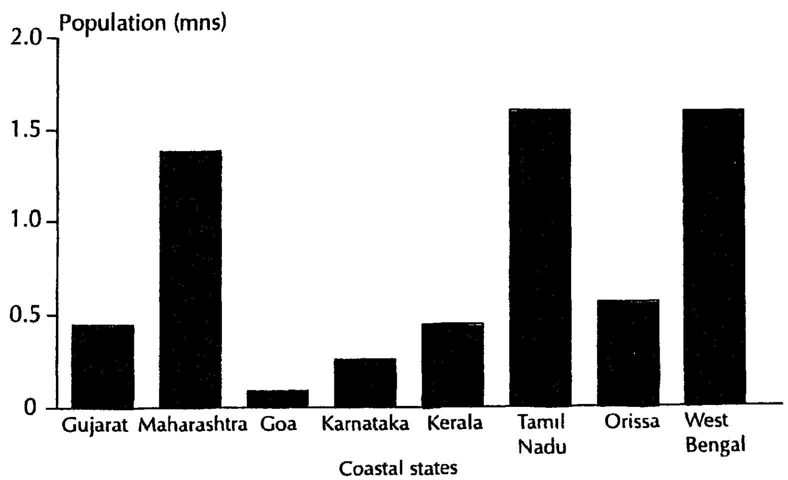


Figure 6. Population at risk, Indian coastal states
Source. JNU (1993)

Table 6. Wetland Categories on the Indian Coast

Categories	Area (km²)
Mudflat	22961
Beach/spit	1465
Shoal/bar	93
Coral reef	1270
Mangroves	3979
Marsh vegetation	370
Beach vegetation	290
Lagoon/backwaters	2132
Flood-prone areas	3437
Coastal dunes	2509
Reclaimed areas	1212
Salt affected areas	697
Salt pans	1617

Source: Space Application Centre (1992)

The response

Studies assessing the impact of rising sea levels indicate that coastlines of both developing and developed nations are vulnerable. However, there is a difference for in the case of the former, the ability to cope with the problem may be limited due to various constraints—financial, informational, and technical. One important advantage, however, lies in the fact that for a number of these nations, the coastal areas are as yet not heavily developed as in the case of the developed world. Hence there is scope for tackling this problem through coastal zone planning.

For a coastal area that may be vulnerable to a SLR, planned coastal development should take account of the relationship between coastal uses and the environmental impact of SLR. There are coastal activities that are very vulnerable to SLR; there are others that aggravate the vulnerability of the area to SLR. For example, current policies of developing the coastline primarily for tourism by allowing beach resorts to come up close to the high tide line at the expense of coastal vegetation and sand dune fields are short-sighted in the context of both normal erosion and the SLR problem. Again, land-use policies that allow construction and habitation close to the river front are often at the expense of mangrove vegetation. Loss of mangroves increases the vulnerability of these river fronts and reduces the option of a retreat in the event of SLR problem in the future. Chart 4 provides some of the human activities that can increase the vulnerability of a region either due to subsidence or a lowered ability to respond to the effects of SLR. Long-term planning should take these interactions into account, and permit only those activities that are amenable to adaptation or retreat if the erosion is serious enough to warrant it. Planning which does not incorporate SLR considerations will in the long run increase the magnitude of economic losses because of the need to redeploy productive resources once employed to the inundated land and reduce the room for adaptive responses to the problem.

There are three main categories of adaptive responses to the SLR problem. These can be classified as: biological, technical and

Chart 4. Coastal zone activities that can increase a region's vulnerability to SLR

Coral mining	Reduces the reef capacity to absorb wave energy
Land reclamation	Increases siltation of reefs and destruction of live corals
Construction of coastal infrastructure	Reduces land available for wetland migration and increases the capital at risk
High coastal population density	Reduces the ability of the region to cope with the impact of SLR and increases the risk to life and property
Groundwater extraction	Causes land subsidence and increases risk of salt water intrusion
Sand dune removal	Affects sand reserves and causes erosior of beach fronts
Sand mining	Causes the beach to erode
Removal of coastal vegetation	Increases the exposure of the beach to higher wave activity and storm surges

institutional or nonstructural (IPCC, 1989). *Biological responses* would consist of those sets of responses that would assist ecological systems to adapt to the environment that changes faster than their natural ability to adapt to it. This would include responses such as assisting wetlands and species to migrate, the setting up of genetic banks, developing crop species that can grow in flooded areas and shifting gradually from aquaculture to mariculture in the coastal zone.

Technical responses involve engineering solutions that could be both of the 'hard' and 'soft' kind. The building of sea walls, groynes, bulkheads, are examples of the former. Artificial beach nourishment is an example of the latter. This set of responses would also include on research on low cost, low technical options for coastal protection, on early warning systems for hurricanes, on design criteria for urban and regional infrastructure in the coastal zone.

Chart 5. Adaptive responses to a sea level rise

	Biological	– Crop species that can grow in flooded areas – wetland migration – Genetic Banks – Species migration
Responses to sea level rise	Technical	– Low cost coastal defense structures – Artificial Beach nourishment – Changes in design criteria for infrastructure – use of GIS in coastal decision-making – use of early warning systems
	Institutional	– Explore alternative coastal uses – Coastal zone planning and implementation – Limit development, sterilization, retreat – Legislation to regulate coastal occupation

Sources: IPCC (1989); National Research Council (1987)

Institutional responses are those that allow coastal resources and land uses to naturally respond to the changing conditions. These responses include developing alternative coastal uses that are less vulnerable to a SLR and that do not aggravate the vulnerability of the area to SLR, increasing the awareness of planners, government officials and builders to its impact, monitoring and assessing the impact of development activities in coastal areas and legislation and zoning for coastal area development. Regulatory and policy measures can be used to encourage and enhance the pace of such responses. Chart 5 lists some of the adaptive responses in summary form.

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